The impact of LTE uplink OOB emissions on PMSE signal quality

In the first part of the in-operation test the impact of LTE UE OOB emissions on the PMSE signal quality, i.e. the SINAD, was investigated. The separation between LTE UE and PMSE receiver was constantly reduced and the RF and PMSE receiver audio output signals were recorded. Measurements were conducted for combinations of four LTE UE and two analogue PMSE receivers with significantly different sensitivity levels. For each measurement, a SINAD deterioration point was determined which represents the attenuation value from which on the SINAD remained below 30 dB.

Figure 19 shows the SINAD curve plotted against the separation between LTE UE 2 and PMSE receiver A for the highest and lowest PMSE frequencies. In line with the LTE OOB interference levels measured previously the SINAD of the PMSE signal at 830.950 MHz, close to the LTE block edge, decreases significantly earlier than that of an 825.925 MHz signal. The difference in this case is approximately 26 dB.

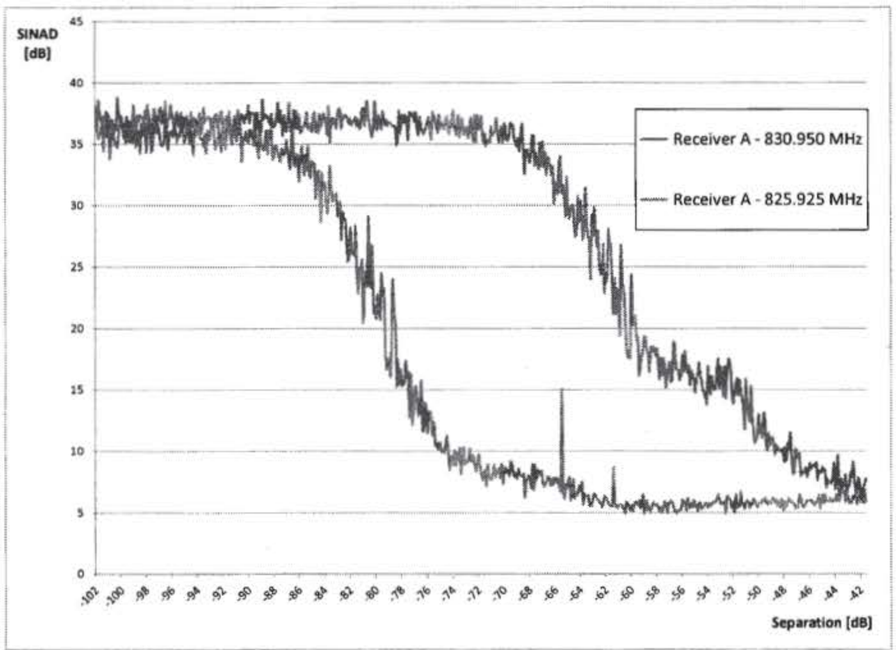

Figure 19: PMSE SINAD vs. separation between LTE UE #2 and PMSE receiver A

In Figure 20 the SINAD curves for two PMSE receivers with different sensitivities are depicted. At both frequencies the SINAD of the more sensitive receiver (Receiver A) decreases earlier than that of the less sensitive system. The difference in both cases is about 8 dB, in line with the difference in sensitivity measured earlier.

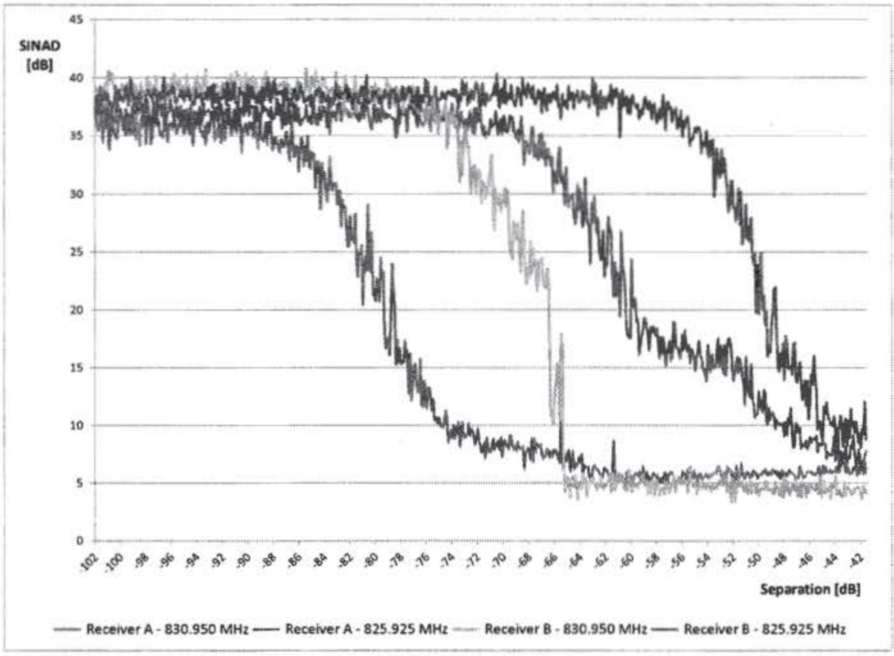

Figure 20: SINAD vs. separation between LTE UE and PMSE receiver for different analogue receiver models

The two digital receivers displayed a slightly different behaviour which is typical for digital systems. At high separation values the SINAD was varying considerably (up to 10 dB) but always remained above 35 dB. From a certain separation on the SINAD suddenly dropped to zero, recovered briefly, and dropped to zero again (Figure **21**).

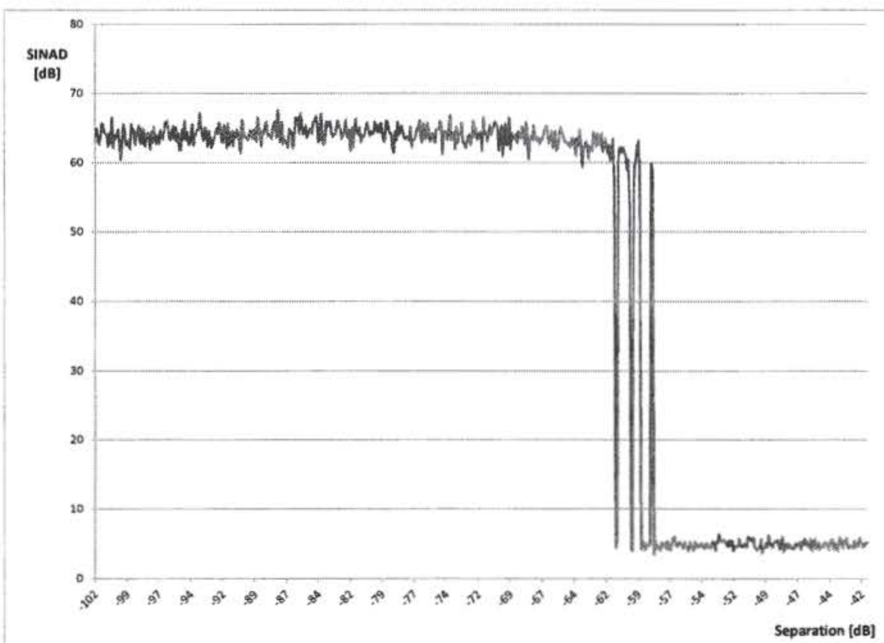

Figure 21: SINAD of digital PMSE receiver D vs. separation (at 825.925 MHz)

For sixteen combinations of LTE UE, PMSE receiver and PMSE frequencies the SINAD deterioration points which correspond to the minimum separation distances between LTE UE and PMSE receiver were determined (Figure 22). At a PMSE frequency of 825.925 MHz the minimum separation ranged from 68 dB to 76 dB, while at 830.950 MHz the minimum separation was 84 dB to 97 dB.

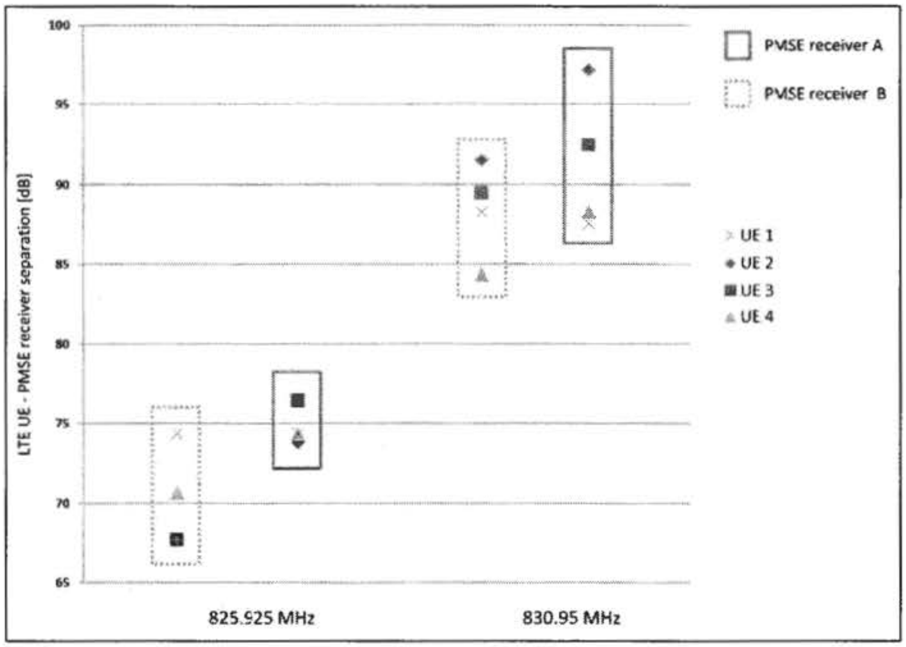

Figure 22: Distribution of SINAD deterioration points for different LTE UEs

SINAD deterioration points were also determined for all five PMSE receivers in combination with the most critical (in terms of OOB interference) LTE UE. At a PMSE frequency of 825.925 MHz the minimum separation ranged from 56 dB to 77 dB, while at 830.950 MHz the minimum separation was 81 dB to 97 dB. Separation values for the two digital systems (receiver models D and E) were lower (between 4 dB and 21 dB) than for the analogue ones. The results for analogue and digital receivers are not directly comparable because the reference metrics for determining the minimum sensitivity level were different (SINAD for the analogue systems and SNR for the digital systems).

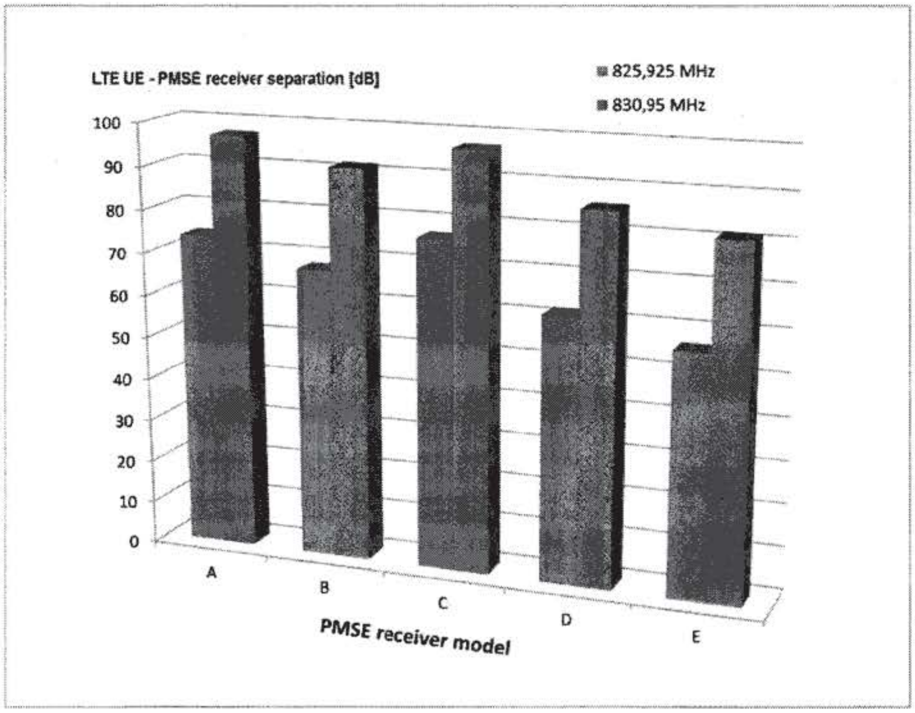

Figure 23: SINAD deterioration points for different PMSE receivers

During the measurements it had been observed that from time to time there were short drops in the SINAD even at high separation values. In order to determine whether or not this was a systematic effect a series of 100 measurements was taken under identical conditions. An analysis of the results showed that the distribution of SINAD values was Gaussian and that the variation in SINAD values was caused by random noise.

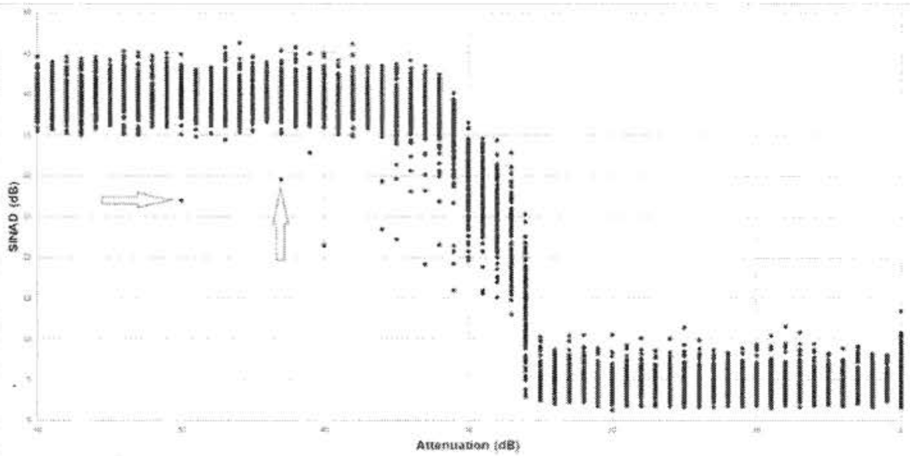

Figure 24: Distribution of SINAD values vs. path attenuation (the red arrows indicate anomalous measuring points)

Figure 25 shows the average and standard deviation for the computed SINAD at each attenuation point for the whole 100 measurements. At attenuation levels between 59 and 45 dB, where occasional spikes were detected, the average SINAD equals 40 dB, while the standard deviation equals 2 dB. It is interesting to note that these values are very similar for the whole range of attenuation, between 59 and 45, which is a first indicator that there is not a general trend within it. Moreover, if we assume the spikes to be caused by pure noise, the distribution of values should follow a Gaussian distribution. In such a distribution 99.7% of the values are spread within $\mu \pm 3*\sigma$, where μ is the average and σ is the standard deviation. For the 100 measurements performed, 99.67% of the points are within those limits and evenly spaced over the attenuation range. Thus we conclude that the main statistics on the range under study are consistent with those of a random noise.

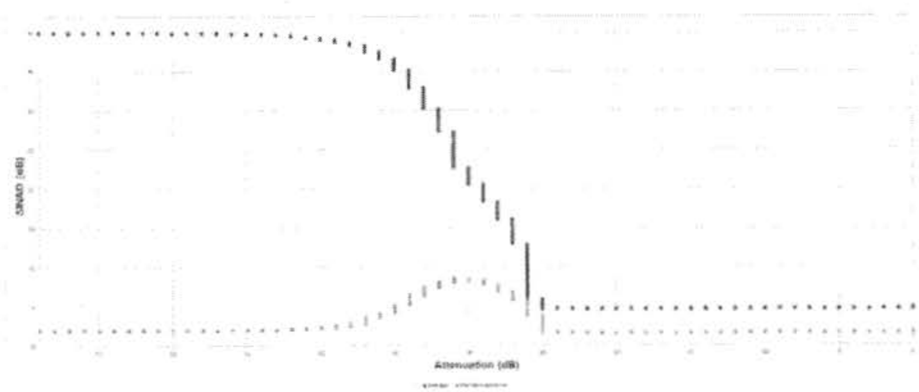

Figure 25: Average and standard deviation for each attenuation level

Impact of increased PMSE RF Signal-to-Noise Ratio

The previous measurements had been made at the minimum sensitivity level of the PMSE receivers at which a SINAD of 30 dB can be maintained, i.e. without any additional margin. To evaluate the behaviour of the PMSE systems when operating with some margin the RF output power, and thus the RF SNR were increased by 10, 20, and 30 dB over the sensitivity level. Figure 26 and Figure 27 show the SINAD curves for the combination of LTE UE 1 and PMSE receiver B operating at 830.950 MHz and 825.925 MHz, resp. Minimum separation values decreased as SNR increased; however, the relation is not strictly linear. An increase in SNR from 10 to 20 dB resulted in a reduction of the minimum separation of about 13 dB.

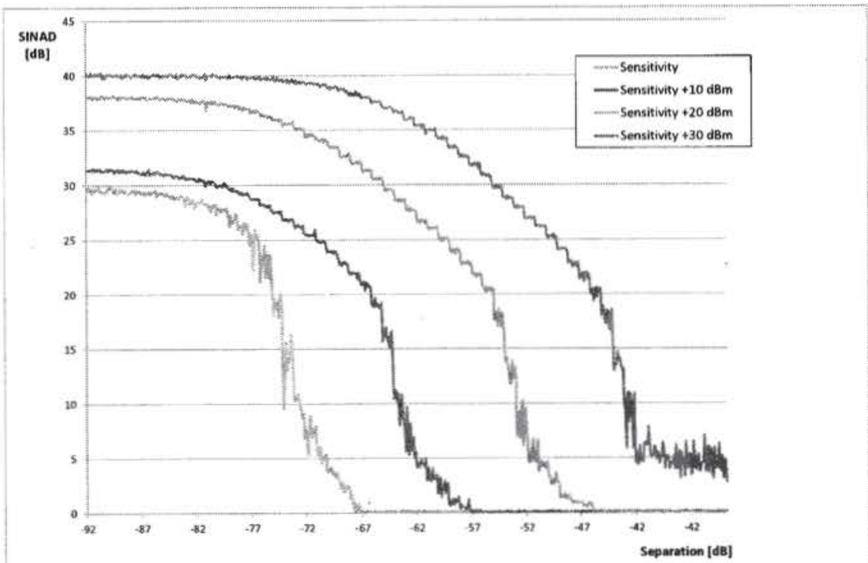

Figure 26: PMSE SINAD at 830.950 MHz

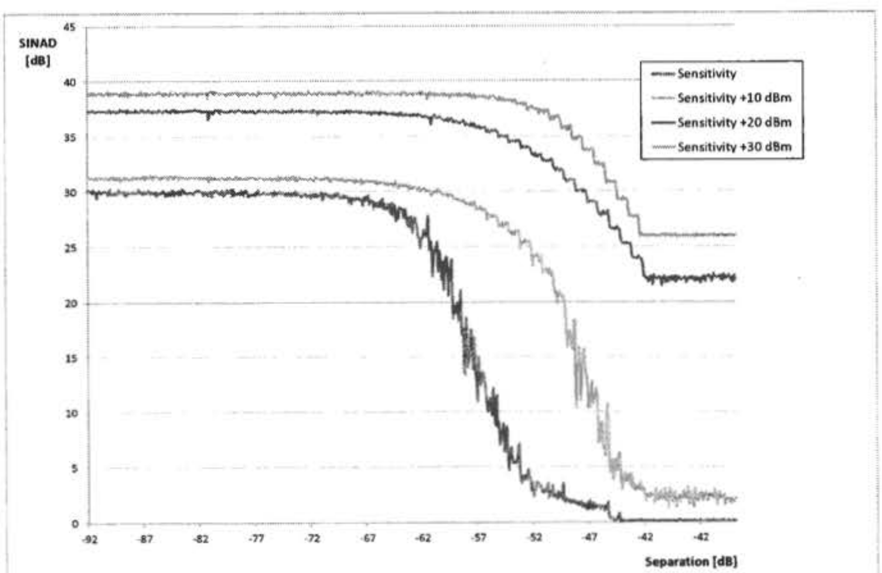

Figure 27: PMSE SINAD at 825.925 MHz

Overall, however, the increase in RF SNR (by 30 dB) and the decrease of the minimum separation were about equal (29.4 dB and 33.7 dB, resp., see Table 4).

	Minimum separation [dB]			
PMSE frequency	**825.925 MHz**		**830.950 MHz**	
FM Tx power level	**Absolute**	**Delta**	**Absolute**	**Delta**
Sensitivity	74,3	-	88,3	-
Sensitivity + 10 dBm	61,8	12,5	79,5	8,8
Sensitivity + 20 dBm	47,9	26,4	64,1	24,2
Sensitivity + 30 dBm	44,9	29,4	54,6	33,7

Table 4: Minimum separation vs. PMSE transmit power for LTE UE1 and PMSE receiver B

Handover measurements

For the handover measurements the path attenuation between LTE UE and PMSE receiver was varied as described above, and the RF and audio signals were recorded. At a predefined value of the variable attenuator A1 which corresponds to a certain LTE UL power level P_{thresh} seen by the LTE pico BS (and the PMSE receiver) the handover from LTE band 20 (800 MHz) to band 7 (2.6 GHz) was initiated (Figure 28). Measurements were made at the six defined PMSE frequencies and for various combinations of LTE UE and PMSE receivers. For each of these combination handovers were initiated at several different values of A1 which had been adapted to the PMSE RF frequencies.

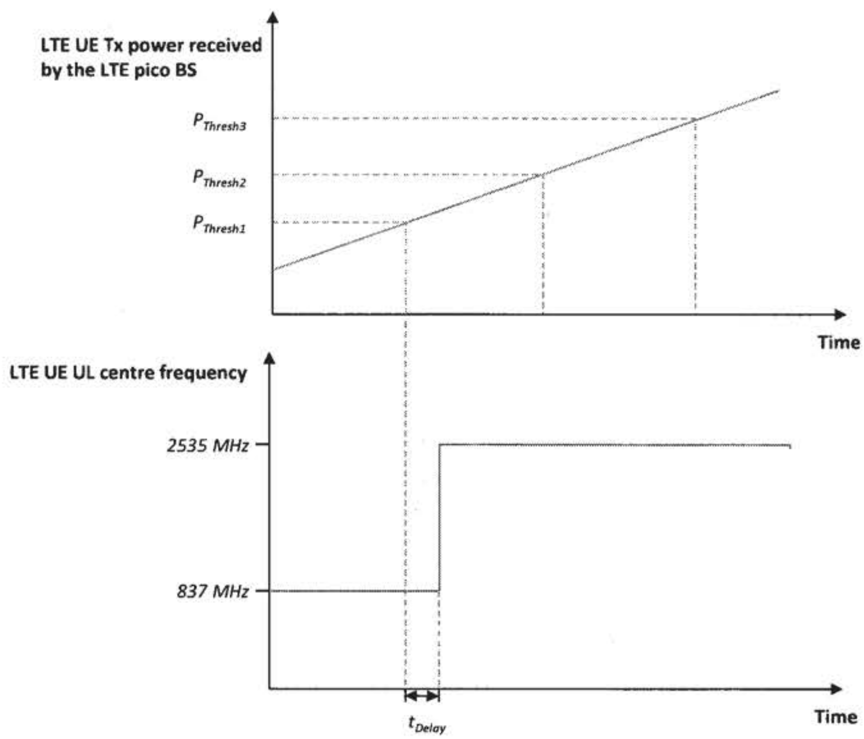

Figure 28: Simulated LTE inter-band handover mechanism

In the vast majority of cases the handover was completed in less than two seconds after initiation. There were a few cases, however, in which the handover took more than 20 seconds to complete. During the time available for the test event it could not be determined whether this delay was caused by the base station emulator or by the LTE UE.

In Figure 29 two exemplary SINAD curves are shown that were measured at 830.950 MHz and 827.950 MHz with the combination of PMSE receiver B and LTE UE 5. As the separation between LTE UE and PMSE receiver was reduced the SINAD decreased. At a certain separation value (68 dB for the 830.095 MHz signal and 61 dB for the 827.950 MHz signal) the handover was initiated, and the SINAD returned to its initial value of 30 dB. When the handover was initiated before the minimum separation was reached no deterioration of the SINAD could be observed.

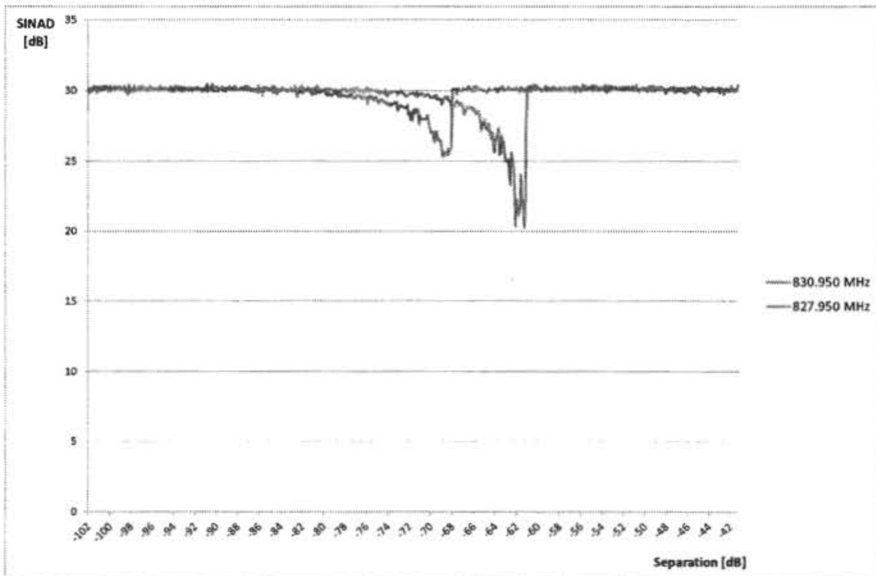

Figure 29: PMSE SINAD vs. separation between LTE UE and PMSE receiver, with LTE handover

During each test run the 821-832 MHz duplex gap spectrum was recorded. This band was later analysed offline for glitches or other artefacts that might have been generated in the course of the handover process and that could cause interference to PMSE signals. The power measured in the duplex gap before, during and after a handover is exemplarily shown in Figure 30. The integration time was 10 ms, equalling the length of one LTE frame. Typically, undershoots and a few spikes, all in the range of 0.1 dB, were observed but no signals with the potential to cause harmful interference to PMSE systems.

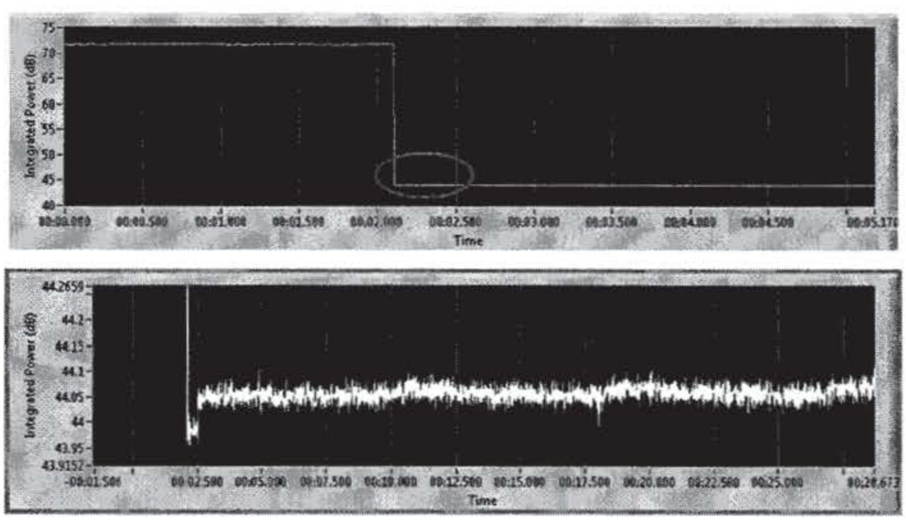

Figure 30: Power measured in the duplex gap (821-832 MHz) during LTE handover.

Start-up test

During the start-up test, an LTE UE was switched on in the presence of a strong 2.6 GHz LTE DL signal (representing a nearby pico BS) and a weaker 800 MHz LTE DL signal (representing a distant macro BS). The path attenuation between the LTE UE (model no. 1) and PMSE receiver (model B) was 47 dB, corresponding to a free-space distance of 6.43 m. The attenuation value was chosen to match that of the IRT measurements [4]. The audio output signal of the PMSE receiver and the 821-832 MHz duplex gap spectrum were recorded. In additional, the audio signal was monitored using a headphone.

Over a period of 60 seconds the device was switched on and off several times. After a few seconds the LTE UE reliably connected to the LTE pico BS, without any interference being audible other than the background noise described earlier which was always present, even in the absence of any LTE signal.

The off-line analysis of the RF power in the duplex gap revealed the presence of a periodic signal with a very low amplitude of less than 0.2 dB above the noise floor. This signal did not cause any audible or visible signal deterioration.

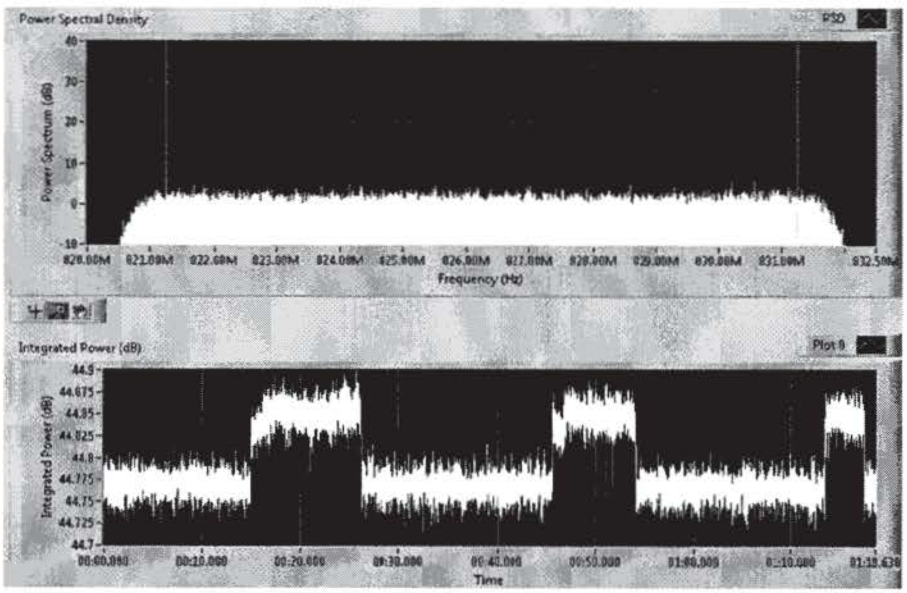

Figure 31: Power measured in the duplex gap (821-832 MHz) during LTE UE start-up.

LTE Picocell Deployment Considerations

This chapter reviews the PMSE protection requirements identified through the measurements and tries to connect them with the technical characteristics of LTE picocells. Its intention is to create a basis for further discussion and research work. Given the diversity of environments in which PMSE systems operate it would go beyond the scope of this report to provide a detailed analysis of the requirements or make recommendations for LTE picocell deployment.

PMSE protection requirements

The measurements yielded a range of values for the separation between PMSE receiver and LTE UE that is required to maintain a SINAD of 30 dB.

How these separation values translate into protection distances depends on the application environment which determines the path loss model that is to be applied. A comparison of the propagation curves of eight LOS and NLOS models is shown in Figure 32.

- ITU-R P.1238-7 [15] covers the range from 900 MHz to 100 GHz. The depicted curves show the path loss for the following conditions: 1) Near-LOS, indoor environment (parameters derived from [16]), transmitter and receiver on the same floor; 2) NLOS indoor (office) environment, transmitter and receiver on the same floor.
- WINNER II 3b NLOS is a model for indoor propagation / hotspots developed in FP7 project WINNER II [17]. Its application is limited to the 2-6 GHz frequency range and distances from 5-100 meters.
- The APWPT model [18] is defined specifically for PMSE systems and takes into account body loss.
- The IEEE 802.11 C model has been used to characterise indoor path loss between PMSE and LTE systems in the 1785-1805 MHz frequency range in ECC Report 191 [19]. The depicted curve shows the path loss for a breaking point of 5 m.
- WINNER II 3b LOS [17] is the line-of-sight version of the aforementioned indoor propagation model.
- The Extended Hata model [20] can be adapted to a variety of environments. The curve depicted below shows the path loss for a range of 0-100 meters under LOS conditions. It is therefore almost identical to the free-space path loss curve.
- The Free-Space path loss curve is calculated from the standard Friis formula.

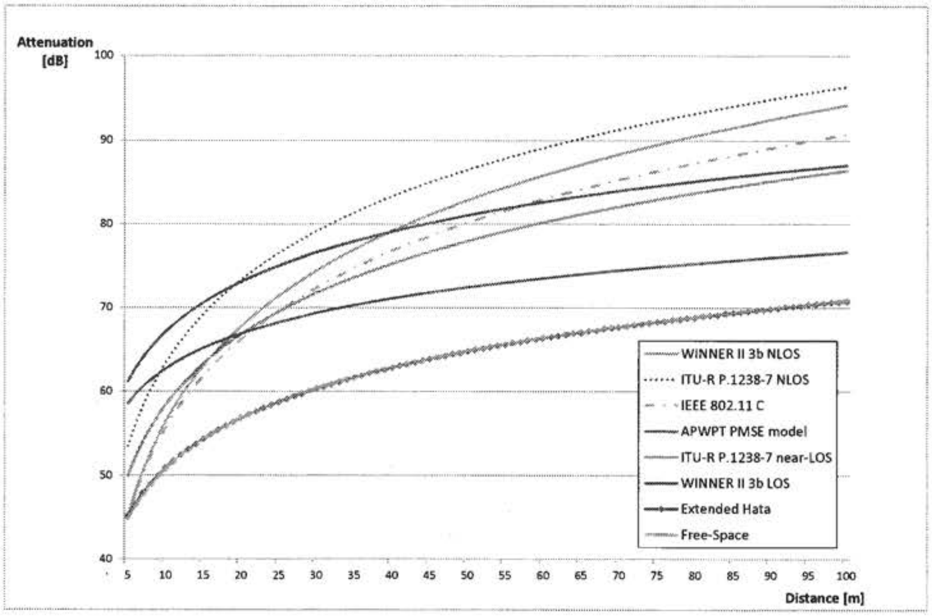

Figure 32: Comparison of path loss models

Exemplary calculations for protection distance for the tested PMSE system are shown in Table 5. The calculations were made for five different path loss models (LOS, near-LOS, and NLOS) and four different link scenarios.

'Worst case' and 'best case' refer to the highest and lowest minimum separation values identified during the measurements, with the PMSE receiver operating at its minimum sensitivity level. The other three scenarios consider an increase in RF signal SNR of 10, 20, and 30 dB, resp. which results in an about equivalent reduction of the minimum separation (see Table 4).

For PMSE systems operating at 830.95 MHZ, i.e. close to the LTE block edge, and at the sensitivity limit separation distances are relatively long, even under NLOS conditions. At 825.925 MHz, minimum separation distances are significantly shorter. At 830.95 MHz a PMSE system will have to operate with an additional signal margin of approximately 20 dB to achieve comparable minimum separation distances.

PMSE receiver operating at the sensitivity limit

PMSE frequency [MHz]	825.925		830.95	
Separation [dB]	Min.	Max.	Min.	Max.
	56.3	76.9	81.4	97.2
Minimum separation distance [m]	Best case	Worst case	Best case	Worst case
LOS	19	201	337	2.080
APWPT PMSE	3	31	52	323
ITU-R P.1238-7 near-LOS	8	46	66	243
IEEE 802.11C	10	41	54	154
ITU-R P.1238-7 NLOS	6	26	35	106

PMSE receiver operating at the sensitivity limit + 10 dB

PMSE frequency [MHz]	825.925		830.95	
Separation [dB]	Min.	Max.	Min.	Max.
	46.3	66.9	71.4	87.2
Minimum separation distance [m]	Best case	Worst case	Best case	Worst case
LOS	6	64	107	658
APWPT PMSE	1	10	16	102
ITU-R P.1238-7 near-LOS	4	20	29	107
IEEE 802.11C	5	21	28	80
ITU-R P.1238-7 NLOS	3	13	17	53

PMSE receiver operating at the sensitivity limit + 20 dB

PMSE frequency [MHz]	825.925		830.95	
Separation [dB]	Min.	Max.	Min.	Max.
	36.3	56.9	61.4	77.2
Minimum separation distance [m]	Best case	Worst case	Best case	Worst case
LOS	2	20	34	208
APWPT PMSE	0	3	5	32
ITU-R P.1238-7 near-LOS	2	9	13	47
IEEE 802.11C	3	11	15	41
ITU-R P.1238-7 NLOS	2	6	9	26

PMSE receiver operating at the sensitivity limit + 30 dB

PMSE frequency [MHz]	825.925		830.95	
Separation [dB]	Min.	Max.	Min.	Max.
	26. Mrz	46.9	51.4	67.2
Minimum separation distance [m]	Best case	Worst case	Best case	Worst case
LOS	1	6	11	66
APWPT PMSE	0	1	2	10
ITU-R P.1238-7 near-LOS	1	4	6	21
IEEE 802.11C	1	6	8	21
ITU-R P.1238-7 NLOS	1	3	4	13

Table 5: Minimum separation distances between PMSE receive rand LTE UE

LTE picocell coverage

Picocells are intend to provide wireless coverage in general, and high-speed broadband access in particular in 'difficult' areas which cannot be served adequately by macro base stations, such as densely populated areas, urban canyons, and indoor locations. For this reason, and as implied by the name, picocell coverage is typically small, in the range of 50 m.

Following is a simplified link budget calculation that relates the PMSE protection distances to the picocell coverage area.

The maximum output power of an LTE Pico BS (also referred to as Local Area BS [21]) is +24 dBm [16]. An LTE UE that is to transfer data at a speed of 2 Mbits per second requires a minimum received signal strength of -91 dBm [22]. The resulting maximum permissible path loss between a LTE pico BS and an LTE UE is 115 dB.

In Table 6 the required separation between PMSE receiver and LTE UE is compared to the picocell link budget. For the minimum and maximum PMSE frequencies that were measured the minimum separation distances are calculated, and the corresponding path loss at the LTE picocell frequency is determined. The upper table shows the calculation for a free-space/LOS scenario, the lower table for a NLOS scenario based on the ITU-R P.1238-7 model from [16].

Scenario: Free-space LOS

PMSE frequency [MHz]	**825.925**	**830.950**
Required separation (worst case) [dB]	77	97
Separation distance [m]	202	2.080
Corresponding path loss at 2535 MHz [dB]	87	107
LTE pico cell maximum path loss at 2535 MHz [dB]	115	
Margin [dB]	28	8

Scenario: ITU-R P.1238-7

PMSE frequency [MHz]	**825.925**	**830.950**
Required separation (worst case) [dB]	77	97
Separation distance [m]	46	243
Corresponding path loss at 2535 MHz [dB]	88	110
LTE pico cell maximum path loss at 2535 MHz [dB]	115	
Margin [dB]	27	5

Table 6: PMSE protection distances and corresponding path losses

In all four cases the resulting margin is positive which means that the picocell coverage area exceeds the PMSE protection range (Figure 33). As stated above these calculations are simplifications; in the ITU-R P.1238-7 scenario, for instance, shadowing and wall penetration losses have not been taken into account. It should therefore be understood that the conclusion from these calculations is <u>not</u> that with a single pico BS a PMSE system could be protected from LTE interference. With a typical capacity of up to 64 users one single pico base station would most probably not be sufficient for most events anyway. Furthermore, the maximum number of users is determined by the bandwidth allocated to each user and by the radio propagation and interference characteristics of the environment.

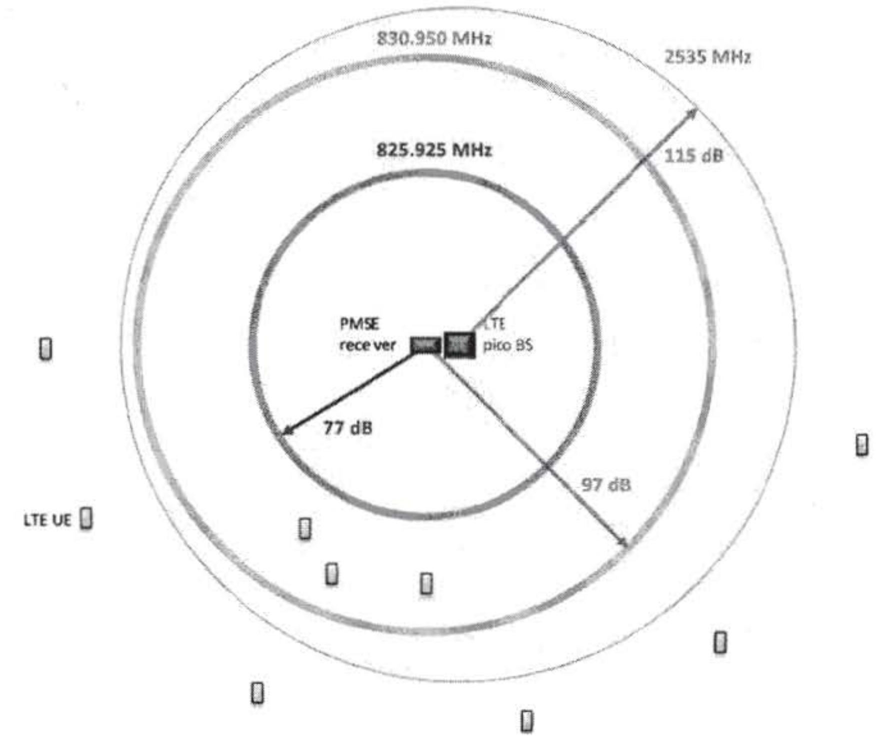

Figure 33: Simplified model of LTE pico BS coverage vs. PMSE protection ranges

It appears advisable to combine a deployment of LTE picocells with careful PMSE frequency and link budget planning. PMSE channels close to the LTE uplink block edge could be assigned to wireless links that have sufficient signal margin while the more critical links that may suffer from higher path loss, shielding and fading would be assigned to those channels further away from the LTE UL band. In this way, the risk of interference would be reduced even further. Alternatively, fewer LTE pico BS might be required to achieve a particular level of interference protection.

Summary and Conclusions

During the November 2013 PMSE-LTE coexistence measurements at the JRC premises in Ispra a total of five PMSE systems and seven LTE UE were tested. The findings of previous studies that LTE UE operating at 837 MHz can generate harmful interference to PMSE systems operating in the 821-832 MHz LTE duplex gap were confirmed. Minimum separations (protection ranges) between LTE UE and PMSE receiver were determined at which an acceptable audio quality (SINAD=30 dB) could be maintained by the PMSE system. The physical separation, i.e. the minimum distance between PMSE receiver and LTE UE at which no harmful interference occurs depends on a number of factors, most of all on the environment which determines the propagation characteristics, the PMSE channel frequency, and the PMSE receiver sensitivity. Consequently, the range of minimum separation distances is very wide; the values determined in this report range from 3 - 200 meters at 825.925 MHz to 35 – 2080 meters at 830.95 MHz (best case NLOS – worst case LOS).

Furthermore, the concept of LTE inter-band handover, from an 800 MHz macro cell to a 2.6 GHz picocell, as a potential interference mitigation technique was evaluated. The movement of an interfering LTE UE operating at 837 MHz towards a PMSE receiver was simulated, and at a certain point in time an inter-band handover was initiated. During each measurement run the audio and RF signals were recorded for later analysis. It was found that in the majority of cases the handover worked fast (within less than 2 seconds) and reliable. When the handover to the 2.6 GHz band occurred outside of the protection range of the PMSE system the SINAD was maintained without deterioration regardless of the distance between LTE UE and PMSE receiver. Before, during, and following the handover no signals with a potential to cause harmful interference and that could be attributed to the handover process were observed in the 821-832 MHz duplex gap.

A start-up test was conducted in which an LTE UE that was in the range of a distant 800 MHz macro base station and a nearby 2.6 GHz pico base station was switched on in the vicinity of a nearby PMSE receiver. The UE repeatedly and reliably connected to the pico BS within a few seconds after it was powered on. No interference to the PMSE signal could be observed during the entire process.

Finally, an 800 MHz and an 1800 MHz analogue PMSE system were operated in parallel with an LTE UE in close distance while the LTE system executed handovers from 800 MHz to 2.6 GHz and back. The audio signal of the 1800 MHz system was monitored for possible interference from cross-modulation. No interference could be observed.

In summary, the conclusions of this report are:

1. Deploying LTE picocells in combination with inter-band handover can avoid or reduce interference from active LTE UE to PMSE if handovers are executed outside the protection range of the PMSE receivers.
2. The deployment of LTE picocells operating in the 2.6 GHz band can avoid or reduce interference from multi-band LTE UE that are activated in the vicinity of a PMSE receiver.
3. As implementation aspects of the picocell and interband-handover concept were not part of the scope of this report further studies will be required to define LTE picocell deployment scenarios and respective requirements.

Annex A: Spectrum and OOB emissions of the tested LTE User Equipment

Maximum peak and average power are displayed.

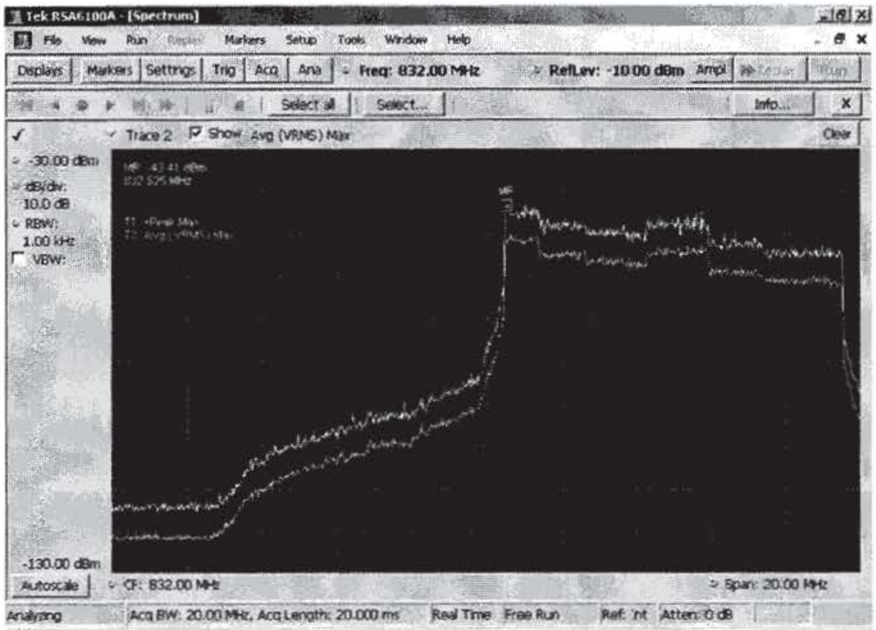

Figure 34: Spectrum of LTE UE #1 (USB modem)

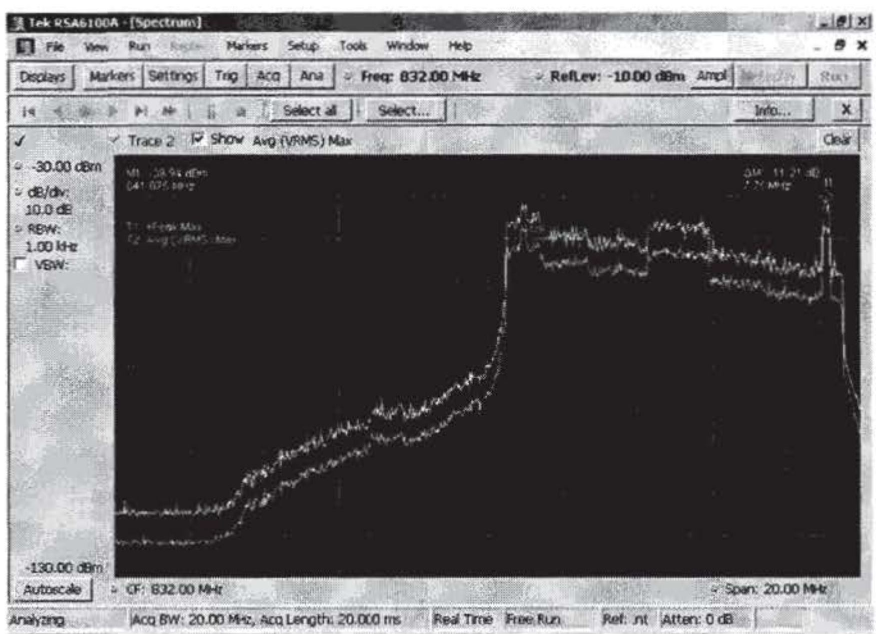

Figure 35: Spectrum of LTE UE #2 (USB modem)

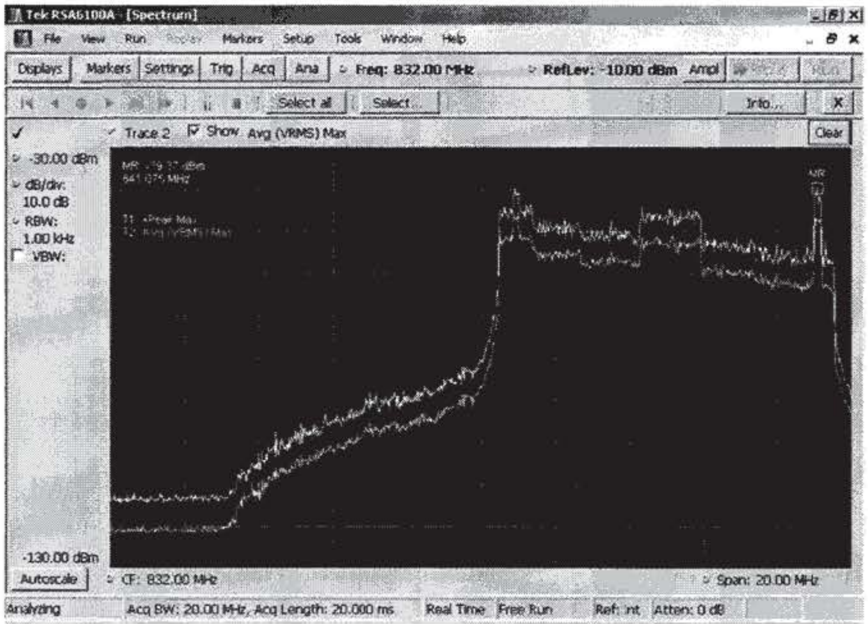

Figure 36: Spectrum of LTE UE #3 (USB modem)

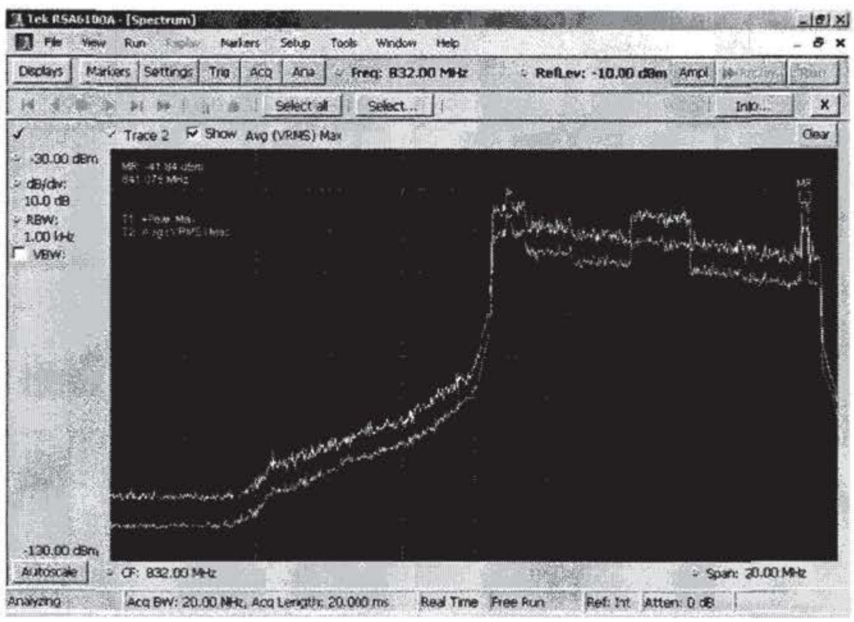

Figure 37: Spectrum of LTE UE #4 (USB modem)

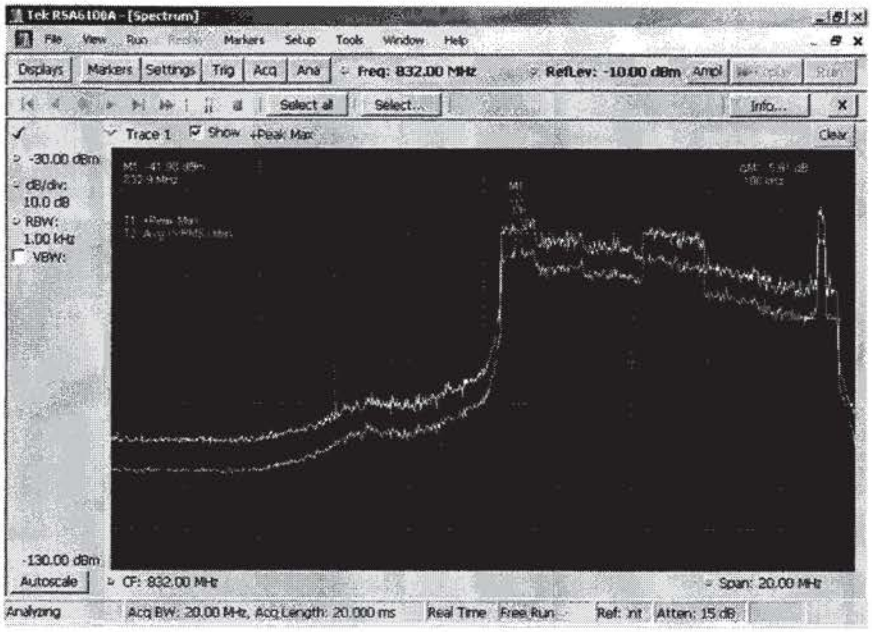

Figure 38: Spectrum of LTE UE #5 (Smartphone)

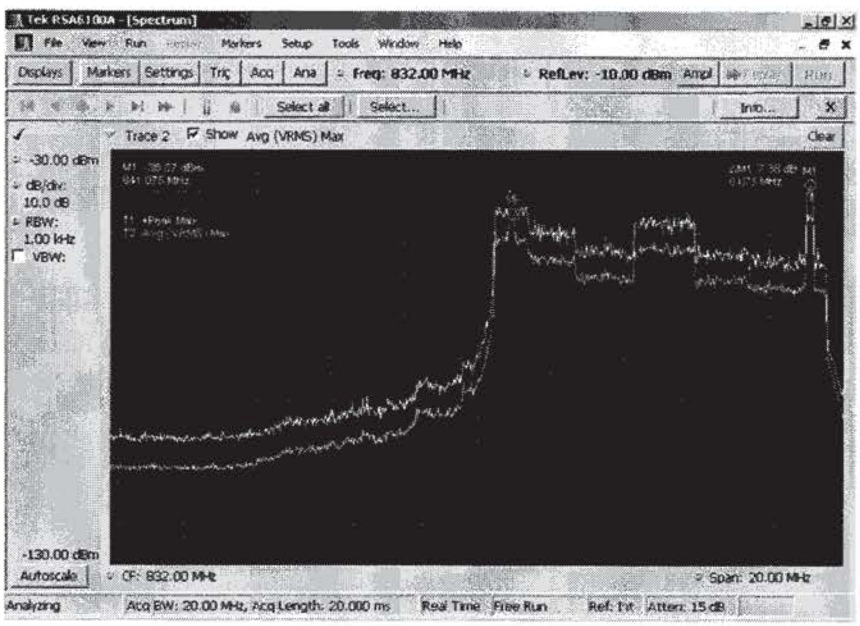

Figure 39: Spectrum of LTE UE #6 (Smartphone)

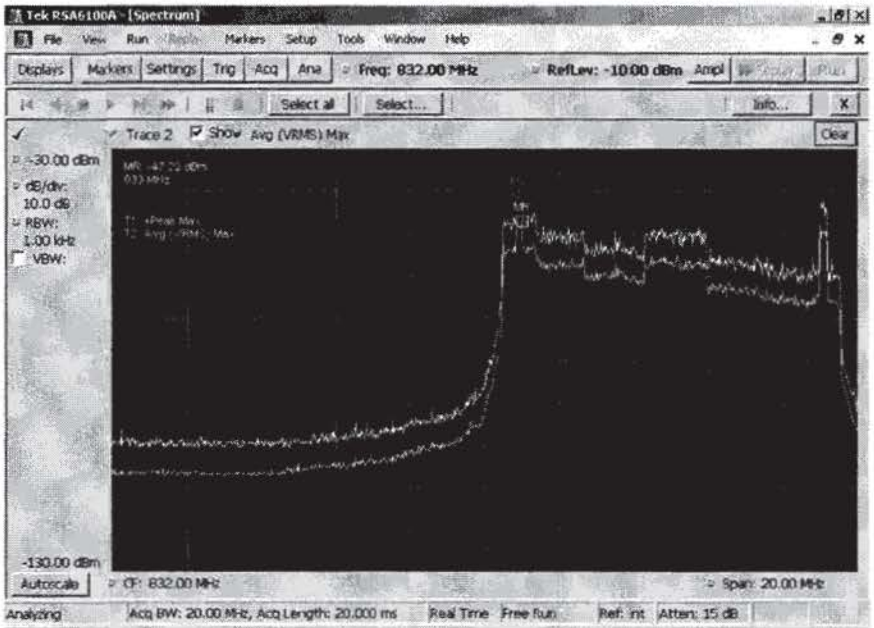

Figure 40: Spectrum of LTE UE #7 (Smartphone)

Glossary

Acronym	Meaning
ADC	Analogue-to-Digital Converter
APWPT	Association of Professional Wireless Production Technologies
BNetzA	Bundesnetzagentur
BS	Base Station
CEPT	European Conference of Postal and Telecommunications Administrations
DAC	Digital-to-Analogue Converter
dB	Decibel
dBm	Decibel milliwatt
DAS	Distributed Antenna Systems
DG CNECT	Directorate General for Communications Networks, Content and Technology
DKE	Deutsche Kommission Elektrotechnik Elektronik Informationstechnik
DL	Downlink
ECC	Electronic Communications Committee
ETSI	European Telecommunication Standards Institute
FDD	Frequency Division Duplex
FM	Frequency Modulation
GSM	Global System for Mobile communications
GSMA	GSM Association
HP	High-Pass
IRT	Institut für Rundfunktechnik
LP	Low-Pass
LTE	Long Term Evolution
LOS	Line Of Sight
NLOS	Non Line Of Sight
OFCOM	[UK] Office of Communications
OOB	Out-Of-Band
PMSE	Programme Making and Special Events
RB	Resource Block

RF	Radio Frequency
SINAD	Signal to Interference And Distortion ratio
SNR	Signal-to-Noise Ratio
SRD	Short Range Device
TBS	Transport Block Size
TBS idx	Transport Block Size index
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication System

Table of Figures

Bibliography

[1] ETSI, *EN 301 357-1 V1.4.1 (2008-11) Electromagnetic compatibility and Radio spectrum Matters (ERM); Cordless audio devices in the range 25 MHz to 2 000 MHz; Part 1: Technical characteristics and test methods,* 2008.

[2] ETSI, *TR 102 546 V1.1.1 (2007-02) Electromagnetic compatibility and Radio spectrum Matters (ERM); Technical characteristics for Professional Wireless Microphone Systems (PWMS); System Reference Document,* 2007.

[3] Electronic Communications Committee (ECC), "Technical conditions for the use of the bands 821-832 MHz and 1785-1805 MHz for wireless radio microphones in the EU," 8 March 2013.

[4] B. Lembke, "LTE interference on analogue and digital PMSE devices," IRT, Munich, 15.10.2013.

[5] APWPT and DKE WG 731.0.8 (DIN/VDE), "A study of LTE interference potential with regard to PMSE operation," 30.06.2012.

[6] P. Granby and J. Hovik, "Report: Investigation of interference between LTE 800 terminals and wireless microphones in the 800 MHz band," 2012.

[7] Bundesnetzagentur (Germany), "WI42- Measurements on the impact of LTE800-User Equipment on wireless microphones, hearing aids and tourguide systems in the frequency range 863 – 865 MHz," 04.01.2013.

[8] Ofcom, "Potential for LTE interference to Wireless Audio," 09.05.2012.

[9] Ofcom, "LTE User Equipment Coexistence with 862 - 870MHz," 11th September 2012.

[10] Fujitsu, *High-capacity Indoor Wireless Solutions: Picocell or Femtocell?.*

[11] A. Kaosher, "Small cells and HetNet," in *UNIK4230: Mobile Communications Spring 2013*, 2013.

[12] The DAS Forum, "Distributed antenna systems (DAS) and small cell technologies distinguished," The DAS Forum, 2013.

[13] "ComTekk SINAD - Distortion Analyzer," ComTekk, [Online]. Available: http://comtekk.us/sinad.htm. [Accessed 27 01 2014].

[14] ETSI, "ETSI TS 102 192-1 V1.1.1 (2004-08) Electromagnetic compatibility and Radio spectrum Matters (ERM); International Technical Characteristics and Test Methods; Part 1: Wireless/Radio Microphones in the 25 MHz to 3 GHz Frequency Range," 2004.

[15] ITU-R, *Recommendation ITU-R P.1238-7 (02/2012) "Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 900 MHz to 100 GHz"*, ITU-R, 2012.

[16] ETSI, *ETSI TR 136 931 V11.0.0 (2012-10) LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) requirements for LTE Pico Node B (3GPP TR 36.931 version 11.0.0 Release 11).*

[17] J. M. L. H. X. Z. T. J. M. N. M. M. C. S. A. H. J. Y. V.-M. H. M. A. R. B. Y. d. J. T. R. Pekka Kyösti, "IST-4-027756 WINNER II D1.1.2 V1.0 WINNER II Channel Models Part II Radio Channel Measurement and Analysis Results," FP7 Project WINNER II, 30/09/2007.

[18] APWPT, "White paper --- Why UHF?".

[19] Electronic Communications Committee (ECC), *ECC Report 191 Adjacent band compatibility between MFCN and PMSE audio applications in the 1785-1805 MHz frequency range*, 2013.

[20] Electronic Communications Committee (ECC), "Manual/PropagationModels/ExtendedHata – SEAMCAT:," [Online]. Available: http://tractool.seamcat.org/wiki/Manual/PropagationModels/ExtendedHata. [Accessed 30 01 2014].

[21] ETSI, *ETSI TS 136 104 V11.6.0 (2013-10) LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception (3GPP TS 36.104 version 11.6.0 Release 11)*, 2013.

[22] *FCC Public Forum Indoor Deployments of Small Cell Sites*, 2011.

[23] Electronic Communications Committee (ECC), "ECC Decision of 30 October 2009 on harmonised conditions for mobile/fixed communications networks (MFCN) operating in the band 790 - 862 MHz," 30 October 2009.

[24] D. Owen, "All you need to know about SINAD," 1999.